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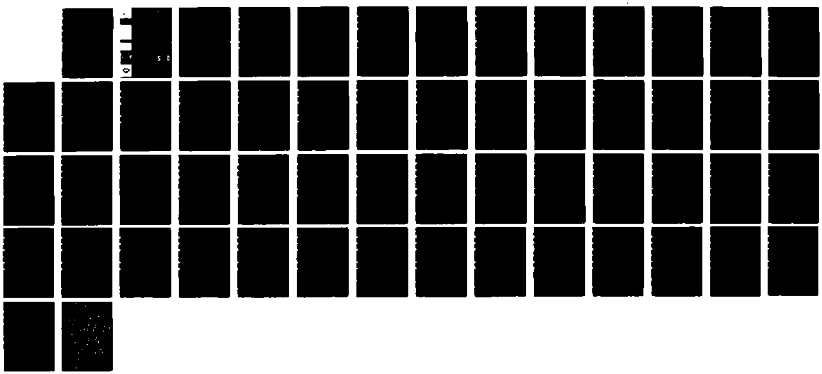

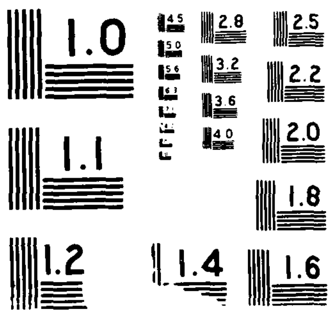
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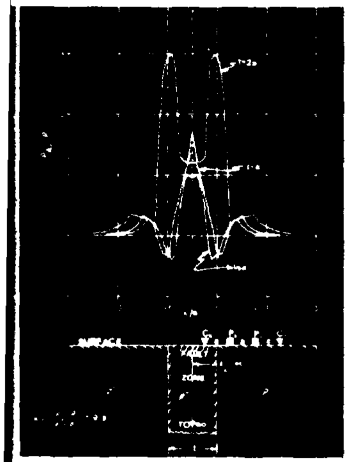
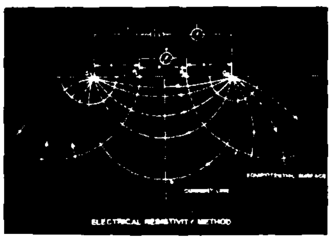
US Army Corps
of Engineers

REPAIR, EVALUATION, MAINTENANCE, AND
REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-GT-9

A SURVEY OF ENGINEERING GEOPHYSICS CAPABILITY AND PRACTICE IN THE CORPS OF ENGINEERS





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March 1988

Final Report

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Civil Works Research Work Unit 32315

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report REMR GT-9	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION See reverse 6b. OFFICE SYMBOL *(If applicable)* WESGH	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State, and ZIP Code)* See reverse	7b. ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)* Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
A Survey of Engineering Geophysics Capability and Practice in the Corps of Engineers

12. PERSONAL AUTHOR(S)
Butler, Dwain K., Wahl, Ronald E., Mitchell, Nolan W. R., Hempen, Gregory L.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final report	FROM Oct 84 TO Sept 86	March 1988	56

16. SUPPLEMENTARY NOTATION
See reverse

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*			
FIELD	GROUP	SUB-GROUP				
			Borehole geophysics	Gravity	Reflection	Seismic
			Engineering geophysics	Microgravity	Refraction	Survey
			Equipment	Radar	Resistivity	

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

A definition and brief overview of engineering geophysics are presented. A historical perspective of engineering geophysics practice and philosophy in general and in the Corps of Engineers are presented. The following three factors are given as primary contributors to a dramatic increase in the scope and acceptance of engineering geophysics in recent years: (a) an ever increasing number of practitioners of engineering geophysics have education and training in geophysics; (b) inexpensive and increasingly sophisticated instrumentation and microcomputers make techniques and procedures possible which were previously impractical for engineering geophysics applications; (c) emergence of a new class of high priority geotechnical problems include hazardous waste-site assessment, groundwater pollution, and military arsenal and range clearance and reclamation for which various geophysical methods are ideally suited. Results of a survey of engineering geophysics capability and practice in the Corps' Districts and Laboratories are presented and

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE *(Include Area Code)* / 22c. OFFICE SYMBOL

6a. NAME OF PERFORMING ORGANIZATION (Continued).

USAEWES, Geotechnical Laboratory
US Army Engineer Division, Missouri River
US Army Engineer District, St. Louis

6c. ADDRESS (Continued).

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210 Tucker Blvd. North, St. Louis, MO 63101-1986

16. SUPPLEMENTARY NOTATION (Continued).

A report of the Geotechnical problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

19. ABSTRACT (Continued).

analyzed. The objective of the survey is to make available a convenient inventory of geophysical equipment and expertise to encourage interchange of equipment and expertise and to ultimately elevate the level of practice of engineering geophysics.

PREFACE

This work was performed from 1 October 1984 to 30 September 1986 by personnel of the Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), the US Army Engineer Missouri River Division Laboratory (MRDL), and the US Army Engineer District, St. Louis (LMS). The work was performed under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program Work Unit 32315, "Geophysical Techniques for Assessment of Existing Structures and Structural Foundations."

The surveys which form the basis of this report were conducted by Messrs. Nolan W. R. Mitchell, MRDL, Gregory L. Hempen, LMS, Ronald E. Wahl, and Dwain K. Butler, EEGD. Useful geophysical capability information was contributed by James E. Clausner, CERC, WES. This report was prepared by Dr. Butler, Principal Investigator for this work unit. Mr. Jerry Huie, Engineering Geology and Rock Mechanic Division, was the Geotechnical (Rock) Problem Area Leader, and Mr. William McCleese was the REMR Program Manager during this investigation.

The work was performed under the general supervision of Drs. Arley G. Franklin, Chief, EEGD, and William F. Marcuson III, Chief, GL. Ms. Odell F. Allen, Information Products Division, Information Technology Laboratory, edited the report.

COL Dwayne G. Lee, CE, was Commander and Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

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A SURVEY OF ENGINEERING GEOPHYSICS CAPABILITY AND PRACTICE IN THE CORPS OF ENGINEERS

PART I: INTRODUCTION

Background

1. The Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program Work Unit "Geophysical Techniques for Assessment of Existing Structures and Structural Foundations" was conceived to address the problems posed to standard geophysical methods by the presence of an existing structure at a site. The problems posed by an existing structure are geometrical and physical. A few examples to illustrate these problems will suffice. The presence of concrete structures or paved access roads defeat or greatly complicate the application of standard geophysical survey methods. Standard interpretation methods used for interpreting electrical resistivity surveys, for example, assume that the surveys are conducted on the surface of a half-space. How then is a resistivity sound conducted on the crest of a dam to be interpreted? Changes in direction of the center line of a dam, levee, or highway or railroad embankment complicate the conduct and interpretation of standard engineering geophysics methods such as electrical resistivity and seismic refraction, which require long, colinear electrode or geophone arrays. The presence of a structure such as a dam moves the points of application of surface geophysical methods further from the foundation materials and hence geometrically attenuates the signatures of normal or anomalous conditions in the foundation. Also, the presence of the structure physically attenuates and distorts signatures and complicates their recognition because of vertical and horizontal variation within the structure. These factors are just examples of problems which must be dealt with or overcome when applying engineering geophysics to existing structure sites.

2. The survey on which this report is based was planned to provide information on Corps' experience in the application of engineering geophysics to existing structure sites and to locate possible field test sites for this research effort. A team including representatives from two Corps field agencies and the US Army Engineer Waterways Experiment Station (WES) was assembled

to design and conduct the surveys. It was the opinion of the team that a great need existed to document the general status of engineering geophysics applications in the Corps. This opinion was based on the personal experiences of the team members as well as prior feedback from the Corps Districts. The status was determined to include in-house capability and expertise as well as the experience in the use of geophysical contractors. In-house capability includes equipment and experienced personnel. Indeed, experienced personnel are the key for either in-house or contractor-conducted engineering geophysics work. Many times a District may have experienced personnel but no in-house geophysical equipment. In such cases, a neighboring District might have equipment which could be borrowed if a convenient inventory of District geophysical equipment were available. Another possibility is that a neighboring District might have a survey crew available to perform geophysical work more expeditiously and/or reliably than a geophysical contractor. If a District lacks experienced geophysical personnel, a need for application of engineering geophysics is identified, and the decision is made to engage a geophysical contractor. Then a sensible procedure is to contact a neighboring District or Corps Laboratory for assistance in preparing a scope of work, reviewing proposals, monitoring field work, and assessing the final report on the work. Knowledge of previous performance of geophysical contractors can be a great aid in evaluating proposals. However, all of the procedures suggested here are contingent on the accessibility of information on in-house geophysical equipment, experienced personnel, and contractor experience. The purpose of this report is to provide a convenient source of information on engineering geophysics capability, experience and practice in the Corps, and to contribute to the best possible applications of this powerful tool for geotechnical and ground-water investigations. Subsequent reports under this Work Unit will address the application of specific geophysical methods to existing structures and structural foundations as well as the complicating factors discussed above.

Engineering Geophysics: Definition and Overview

Definition

3. The term engineering geophysics is applied to a subdiscipline of exploration or applied geophysics involving geotechnical and ground-water

applications. Briefly, the techniques or methods of engineering geophysics include electrical and electromagnetic methods, seismic methods, magnetic methods, gravity methods, radioactivity methods, geothermal methods, and geochemical methods. Generally the methods used in engineering geophysics are similar to those used in other areas of exploration geophysics, but the depths of interest are shallower, the areal scales of application are smaller, and the required resolution is higher.

4. Although they are not the focus of this report, acoustic tools can provide images of the underwater portion of structures and the bottom where water turbidity, currents, or other conditions preclude an optical system or diver observation. Also, acoustic subbottom profilers are sometimes more cost effective than conventional seismic methods, particularly in shallow water.

Overview

5. A comprehensive list of projects or problems to which engineering geophysics can or has been applied would include ground-water exploration and resource assessment, ground-water contamination detection and mapping, hazardous wastesite assessment, site investigations for power plant and dam siting, existing structure assessment, highway and railroad route assessments, cavity detection and mapping including abandoned mines, physical property determinations for analytical and numerical modeling (e.g., dynamic analyses of structures), seepage mapping and monitoring, shallow geological mapping, and archaeological assessments. References that are particularly appropriate as background for this report and for those interested and/or involved in engineering geophysics are Engineer Manual EM 1110-1-1802, Geophysical Exploration (Headquarters, Department of the Army 1979); Applied Geophysics for Engineers and Geologists (Griffiths and King 1965); Applied Geophysics (Telford et al. 1976); and Geophysics (Dobecki and Romig 1985).

6. In the past, the use of geophysics for geotechnical applications was justified as a cost-effective alternative to closely spaced exploratory boreholes or "when all else fails." This is basically the philosophy expressed in the following:

> In locating and correlating geologic features, indirect geophysical techniques are intended to supplement direct methods insomuch as practical. There is no substitute for a direct assessment of site conditions, i.e., borings pits, trenches, etc. By judicious planning, the number of borings required for

> subsurface definition can be greatly reduced if the proper geophysical methods are chosen to supplement the direct investigational program. (Headquarters, Department of the Army 1979).

> ...engineering recognizes geophysics as a tool which can often give important information about a site as effectively and more cheaply than a very large number of boreholes...geophysical methods are often only tried when the failure of drilling methods has shown in the problem to be complex, and simple problems which could be cheaply solved by geophysics with a limited amount of borehole control are wastefully dealt with by extensive drilling. (Griffiths and King 1965).

Although the facts discussed in the above quotes are still true, at least three factors are evident as primary contributors to a dramatic increase in the scope and acceptance of engineering geophysics in recent years. First, an ever increasing number of practitioners of engineering geophysics have education and training as geophysicists. Secondly, inexpensive, increasingly sophisticated instrumentation and microcomputers make techniques and procedures possible which were previously impractical for engineering geophysics, and third, emergence of a new class of high priority geotechnical problems, including hazardous wastesite assessment, ground-water pollution, and military arsenal and range clearance and reclamation for various geophysical methods are ideally suited. A quote from Dobecki and Romig emphasizes this change in perspective of engineering geophysics:

> Geophysical applications to geotechnical and ground-water problems...have leaped from a role of merely a sensible, cost effective substitute for boreholes or a scapegoat in difficult subsurface geology to one in which they are often the only means by which an important problem can be addressed. (Dobecki and Romig 1985).

While the changes in perspective and philosophy expressed by this quote are beneficial, the potential user of engineering geophysics is cautioned not to forget that there is no substitute for ground truth as determined by borings, test pits, and trenches, and any geophysical survey should be planned with this in mind; ground truth is necessary to validate and even correct geophysical interpretations; and, while the combined use of geophysical and (ground truth) boring investigations greatly improve the chances of finding important (geological) details, the combination is not foolproof (Headquarters, Department of the Army 1979).

7. Engineering geophysics is a quantitative science and geophysicists that address problems or projects from the perspective of the scientific method of inquiry. The engineering geophysicist expresses his results in quantitative terms with an associated statement of accuracy; but with full knowledge of the limitations and assumptions of the methods and results, the geophysicist must express the fundamental nonuniqueness of many of his results. These factors often put the engineering geophysicist in an uncomfortable or adversarial posture with geologists, often demonstrating a qualitative, observational approach to problems, and with engineers whose missions require a pragmatic, deterministic approach to problems. Generally the solution to all such problems of the nature just described (arising from philosophical bases) is more effective communication, which results when geologists, geophysicists, and engineers speak the same language. Fortunately more effective interdisciplinary education programs at all levels are producing engineering geologists, engineering geophysicists, and geotechnical engineers who can better understand and appreciate the capabilities of each other. This is enabling more effective team efforts for solving complex geotechnical and ground-water problems.

Historical Perspective

8. Dobecki and Romig (1985) present a historical perspective of the science of engineering geophysics in general, which will not be repeated here. Evidence of the increase scope and acceptance of engineering geophysics in recent years is provided by the greatly increased publication and professional society activity in engineering geophysics. In 1978 the Society of Exploration Geophysicists formed the Engineering and Ground-Water Geophysics Committee and has had at least two Engineering and Ground-Water Sessions at its annual meetings since 1978. The American Society of Civil Engineers has organized several specialty conferences on engineering geophysics in the past 10 years, and the Association of Engineering Geologists typically will have at least one session on engineering geophysics at its annual meetings. Likewise, the National Water Well Association has organized several specialty conferences on surface and borehole methods in ground-water investigations in

recent years, and a significant percentage of the papers in Ground-Water Monitoring each month will involve engineering geophysics applications.

9. The history of engineering geophysics in the Corps of Engineers closely parallels with that of the science in general. The predecessor of EM 1110-1-1802, Geophysical Exploration (Headquarters, Department of the Army 1979), was a 1948 engineer manual with the same title which covered only the seismic refraction and electrical resistivity surveying methods. Emphasis in the 1948 manual is on the use of geophysics as a cost-effective alternative to extensive drilling programs, echoing the philosophy expressed in the quote from Griffiths and King (1969). By 1979 the use of engineering geophysics in the Corps had expanded considerably and the new engineer manual includes extensive coverage of surface, borehole, and waterborne seismic surveying methods (refraction, reflection, surface wave, crosshole, uphole/downhole methods), electrical resistivity methods, gravity methods, and nearly all types of borehole geophysical logging. Although techniques such as magnetic, electromagnetic (EM), ground penetrating radar, spontaneous potential, and airborne methods are not considered in detail, applicability of these methods is included in extensive tabulations. An elevation of the status of engineering geophysics in the Corps is evident in the general philosophy expressed in EM 1110-1-1802 (Headquarters, Department of the Army 1979). Also, considerably more emphasis is placed on the usefulness of geophysical survey results in planning exploratory drilling programs and in engineering analyses and design. Availability of engineering geophysics training in the Corps has been limited to 1 or 2 hr lectures in a drilling and sampling short course and in an earthquake soils response short course and as one of several subject areas covered in Engineering Geology I and II, two semester-length courses conducted on a university campus.

10. Since 1979, applications of engineering geophysics in the Corps of Engineers have expanded considerably, and the next engineer manual on geophysical exploration will undoubtedly contain detailed sections on magnetic surveying for hazardous wastesite assessments and archaeological studies, electromagnetic methods for ground-water exploration and hazardous wastesite studies, high resolution gravity surveying (microgravity), ground penetrating radar surveying, shallow seismic reflection methods, acoustic emission seismology, and spontaneous potential methods for seepage investigations. Also, the next engineer manual will include descriptions of microcomputers and

software for geophysical data processing and interpretation. The number of engineering geophysicists and others with engineering geophysics training in the Corps has increased in recent years. This trend has helped to improve the quality of engineering geophysics work performed in-house and the capability to select, monitor, and assess the work performed by the contractors. This trend also increased Corps' awareness of the full potential of engineering geophysics. A separate engineering geophysics short course will be offered in response to the increased interest and applications.

11. In addition to the present research effort under the REMR Research Program, two other research efforts have been conducted by the Corps of Engineers which were directed exclusively to the advancement of the state of the art in engineering geophysics. From 1975 to 1981 a major research effort was conducted for the development of techniques for the detection and delineation of subsurface cavities. Results of this effort are chronicled in reports by Butler (1977), Butler and Murphy (1980), Butler (1983), Curro (1983), Cooper (1983), Butler, Whitten, and Smith (1983), and Ballard (1983). A research effort directed to the development of analytical and data processing techniques in engineering geophysics was conducted from 1978 to 1982 and is documented in a report by Butler et al. (1982). Another indication of the increased acceptance of engineering geophysics in the Corps is the willingness of Corps Districts to contribute funding to applied research and to conduct field evaluations of engineering geophysics methodology. Two notable examples are the joint REMR/Little Rock District funding of field research at Beaver Dam, Ark., and the funding of a novel field assessment of engineering geophysics methodology for detection and monitoring of potential sinkhole features along the Sunny Point Military Access Railroad, N.C., by the Wilmington District.

12. This new perception and status of engineering geophysics in the Corps is in stark contrast to the state of affairs in the past when geophysics held little higher status than water witching. Engineering geophysics is increasingly perceived as an integral part of programs for exploration and site assessment. For each field situation there are some geophysical methods which are applicable and some which are not applicable, and a geophysical exploration program should be planned specifically for each field situation. If the right geophysical methods and field procedures are applied to each

field situation, the success rate and confidence in engineering geophysics will rise.

Scope

13. Part II of this report discusses the methodology used for the survey of the Corps Districts and Laboratories. The actual results of the survey are presented and discussed in Parts III and IV. Finally, some conclusions based on the survey results and recommendations for utilization of the results are presented in Part V.

PART II: SURVEY METHODOLOGY

General Approach

14. Because of the number of Corps Districts, the survey task was assigned to four investigators. To some extent, each investigator was assigned districts which are geographically close to his location. In this way each investigator could better identify with the districts, follow through in obtaining responses to the survey, and make site visits if desirable. The following tabulation identifies the District assignments:

Investigator	Division	District
Ronald Wahl, WES	South Pacific	Los Angeles Sacramento San Francisco
	South Atlantic	Jacksonville Mobile Savannah Wilmington Charleston
	North Pacific	Walla Walla
Nolan Mitchell, US Army Engineer Missouri River Division Laboratory (MRDL)	Missouri River	Omaha Kansas City Division Laboratory
	North Central	Buffalo Chicago Detroit Rock Island St. Paul
	North Pacific	Portland
Gregory Hempen, US Army Engineer St. Louis District (LMS)	Lower Mississippi Valley	Memphis New Orleans St. Louis Vicksburg
	Ohio River	Huntington Louisville Nashville Pittsburgh
	North Pacific	Alaska Seattle

Investigator	Division	District
Dwain Butler, WES	Southwestern	Albuquerque Galveston Fort Worth Little Rock Tulsa
	North Atlantic	New York Norfolk Baltimore Philadelphia
	Corps Laboratories	WES (Geotechnical Laboratory (GL), Environmental Laboratory (EL), Structures Laboratory (SL), Coastal Engineering Reserch Center (CERC), Engineer Topographic Laboratory (ETL), Cold Regions Research and Engineering Laboratory (CRREL), and Construction Engineering Research Laboratory (CERL)

15. An initial, short survey form was sent to District Geologists or other appropriate initial points of contact for each District. The purposes of the short survey form were to establish contact, explain the survey, determine the Districts for which a follow-on detailed survey form was appropriate, and determine points of contact for all follow-on work. Telephone contact between the investigators and the District Geologists occurred as necessary or appropriate to encourage completion of the survey forms, clarify points of confusion, and obtain more detailed information. District Geologists and other points of contact are given in Appendix A in the order presented in the above tabulation.

Survey Form Content and Strategy

16. The short survey form (Figure 1) explains the REMR Research Program, the geophysical research project, and the purpose of the survey of the Corps Districts. Question 1 requests information needed by the investigators to determine which districts warranted either a partial or complete follow-on

The Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program is a major Corps of Engineers Civil Works program intended to directly address problems associated with existing Corps projects. The geotechnical problem area is only one of seven problem areas being addressed by the REMR Research Program.

One of the projects under the geotechnical problem area, "Geophysical Techniques for Assessment of Existing Structural Foundations," addresses the need for remote, "nondestructive" methods for assessing foundation conditions beneath existing structures. Dwain Butler, US Army Engineer Waterways Experiment Station (WES), Ronald Wahl, WES, Nolan Mitchell, Missouri River Division Laboratory, and Greg Hempen, St. Louis District, are associate investigators for this project. The project objectives are to (a) assess the current status of applied geophysics in the Corps, (b) determine the most prevalent conditions or problems affecting existing structural foundations at Corps projects (karst features, fracture zones, differential settlement, etc.), and (c) develop new or adapt existing geophysical methods to address existing foundation problems.

We hope to obtain information to enable us to achieve the above objectives by contacting each Corps District through the District Geologists. We want the contacts to be as personal and informal as possible, and promise that very little of your time will be required. We also hope to identify possible field evaluation test sites for the project. Small-scale site investigations under the project will be entirely funded by the project, but larger-scale cost-sharing investigations at the request of a District are possible.

Please furnish the following information:

1. Has your District used geophysics on any of your projects within the past 10 years (either through in-house or consulting services)?
   Yes___, No___.

   Do you have in-house geophysical equipment and/or expertise?
   Yes___, No___.

   Point of contact for further information (Name, Telephone Number) if not yourself:

   ____

2. Do you plan to use geophysics at a project site in the near future, <u>or</u> do you have ongoing work at a site at which you feel geophysics could assist you in assessing subsurface conditions?
   Yes___, No___.

Point of contact if not yourself:

____

Figure 1. Short survey form

detailed survey. Question 2 was to locate possible field test sites for the project.

17. The complete detailed survey consisted of three forms, as shown in Figure 2, requesting information on (a) in-house geophysical capabilities (Figure 2a), (b) the use of geophysical contractors (Figure 2b), and (c) recent use of geophysics (Figure 2c). Short responses are required in most cases, and examples are given on each form to illustrate the type of responses desired. A question at the bottom of the "recent use" form (Figure 2c) requests information on current foundation investigation needs; this information will allow research to be focused on major problem areas and aid in the selection of field test sites.

IN-HOUSE GEOPHYSICAL CAPABILITIES -- __________ DISTRICT

	Equipment		Personnel		
Geophysical Method	Rent or Own	Type (Description, Manufacturer, Model No.)	Average Crew Size	Qualified Operators	Qualified Interpreters
Examples:					
Seismic Refraction	Own	12-Channel Seismograph, EG&G, Model 1210	3	1	1
Electrical Resistivity	Rent	Resistivity Meter, Bison, Model 2350	3	2	1
Seismic Refraction					
Seismic Reflection					
Other Seismic Methods (Specify)					
Electrical Resistivity ______ Horizontal Profiling ______ Vertical Sounding (Check)					
Other Electrical Methods (Specify)					
Gravity					
Magnetic Methods					
Radar					
Other Electromagnetic Methods (Specify)					
Borehole Logging (List Log Types)					

Figure 2a. Detailed survey form, in-house capabilities

USE OF GEOPHYSICAL CONTRACTORS -- __________ DISTRICT

Geophysical Method	Contractor	Number of Qualified In-House Reviewers of Contractor Results	Under Similar Circumstances Would You Contract for These Services Again? (Yes or NO)	Remarks
Example: Electrical Resistivity --Horizontal Profiling and Vertical Sounding	Reputable Geophysics, Inc. Fly by Night Geophysics	2 2	Yes No	 Results not interpreted

Figure 2b. Use of geophysical contractors

RECENT USE OF GEOPHYSICS AT ________ DISTRICT PROJECTS

Project Name	Geophysical Methods Used	In-House (I) or Contract (C)	Purpose	Did Geophysics Contribute Significantly to the Project? (Yes or No)	Why or Why Not?
Examples: No-Name Dam Seepage Study	Seismic Refraction, Electrical resistivity	I	Find path of seepage beneath earth-fill dam.	No	Nothing anomalous was seen in resistivity data; refraction data very poor quality.

What foundation conditions are you aware of that may warrant additional investigation at existing structure sites in your District?
(Example: Determine extent of possible void beneath stilling basin slab at Highwater Dam.)

Figure 2c. Recent use of geophysics

PART III: SURVEY RESULTS, CORPS DISTRICTS

Summary of Survey Response

18. Of the 36 Conus Corps of Engineer Districts contacted, 34 responses of the short survey form were received, and 30 responses of the detailed survey form were received. Responses to the short survey form can be summarized with the following tabulations of yes/no responses to three questions:

	Yes	No
Has your District used geophysics within the past 10 years?	29	5
Do you have in-house geophysical equipment and/or expertise?	30	4
Do you plan to use geophysics in the near future or do you have ongoing work at a site at which you feel geophysics could help in assessing subsurface conditions?	25	9

In the past 10 years (at least) engineering geophysics has been utilized in one form or another by the majority of Corps Districts, and the majority of the Corps Districts have at least some geophysical equipment and expertise.

19. The detailed survey forms are more difficult to summarize, so the following summary only highlights the results (for this part of the survey analyses, the Corps Laboratories as well as other Federal Government agencies are considered as contractors):

Number of Districts with in-house geophysical equipment	26
Number of Districts indicating no in-house geophysical expertise	6
Number of Districts renting geophysical equipment	2
Number of Districts using geophysical contractors (Corps Laboratories considered as "contractors")	30
Number of different geophysical contractors used	46
Number of contractors used more than once (not necessarily by the same District)	12
Number of Districts indicating dissatisfaction with contractor performance on one or more occasions	7

Number of other Federal agencies used as contractors by the Districts	4
Number of Districts or Division Laboratories used as contractors by other Districts	3
Number of Districts using multiple geophysical methods	24

Detailed Presentation of Survey Response

20. There was considerable variation in the amount of detail given and the time taken to complete the detailed survey forms by the various Districts; this variation must be remembered when generalizations are made in this report or by the reader. The old adage "beggars can't be choosers" probably should be applied to attempts like the present survey to obtain information. Also, the data are probably not complete due to limited corporate memory in large organizations with changing personnel. The following sections are attempts to collate the information contained in the survey into useful and easily digested tabulations.

In-house geophysical capability

21. Table 1 lists the geophysical equipment owned or in some cases rented by the Districts. The description of the equipment in Table 1 is as complete as possible, indicating manufacturer and model number. Also indicated in Table 1 are the average crew size, number of qualified operators of the equipment, and number of qualified interpreters of data acquired with the equipment. The in-house personnel are generally geologists and engineers who conduct geophysical surveys or interpret or review geophysical results when needed but otherwise have other duties. Of the 26 Districts with in-house geophysical equipment, three Districts indicated that the equipment was inoperative, and five other Districts indicated no qualified operators and/or interpreters for in-house equipment. A summary of the type of equipment owned by the 26 Districts is shown in Table 2. Seismic surveying equipment is owned by 22 Districts and ranges from antiquated one-channel interval timers to one-channel signal enhancement seismographs to 12-channel signal enhancement seismographs. Electrical resistivity equipment is owned by 14 Districts, and 14 Districts have borehole geophysical logging equipment. Three Districts have magnetometers, and only one District owns a gravity meter.

Table 1

Corps of Engineers Districts In-House Geophysical Equipment and Expertise

District	Equipment	Own or Rent	Typical* Crew Size	Qualified* Operators	Qualified* Interpreters
Los Angeles	12-channel seismographs Nimbus Model ES-1200; EG&G Model 1225	Own	2	2	2
Sacramento	12-channel seismograph, Nimbus Model 125	Own	2	2	2
	Seismograph, Nimbus Model ED-100	Own	2	2	2
	6-channel seismograph, Nimbus Model ES-6	Own	2	2	2
San Francisco	Seismometer, Dynametric Model 1178 with radio link	Own	--	--	1
	Magnetometer, Sharpe Model MF-1R-100	Own	--	--	--
Mobile	1-channel blast Seismograph, Model VS-1200	Own	1	1	1
	1-channel seismograph, Bison Model 1570B	Own	2	2	1
	Resistivity meter, Soil Test Model R-41C	Own	1	2	1
	Borehole logger, Geologger	Own	1	2	1
Savannah	12-channel seismograph, Geospace Model GT-2B	Own	2	2	1
	Resistivity meter, Soil Test Model R-40	Own	2	2	2
	Borehole logger, Gearhart-Owen Model 3200	Own	2	1	1
Wilmington	12-channel seismograph, EG&G Model 120F	Own	2	1	1
	Resistivity meter, Bison Model 2350A	Own	2	--	--
	Magnetometer, EG&G Model G816	Own	1	1	1
Walla Walla	Seismograph	Own	2	2	4
	8mm borehole camera	Own	2	2	1
Portland	1-channel seismograph, Bison Model 1570B	Own	3	1	1
	Recording interval timer, Electro Tech Model ER-75	Own	--	--	--
	Borehole logger, SP, Resistivity, Nat. Gamma, Caliper	Own	2	3	2
Alaska	Seismograph, Soil Test Model MD-9A	Own	2	2	1
	VLF Resistivity meter, Geonics Model EM16R	Own	2	1	1
Seattle	12-channel seismograph EG&G Model 1210	Own	2	1	1
	Resistivity meter	Own	2	1	1
	Gravity meter, LaCoste and Romberg Model D4	Own	1	1	1
	Magnetometer, Geometrics Model G-816	Own	1	1	1
	Borehole logger, Dresser-Atlas	Rent	2	1	1
Buffalo	1-channel seismograph, Bison Model 1570C	Own	2	3	2
Rock Island	1-channel seismograph, EG&G	Own	2	1	1
St. Paul	1-channel seismograph Bison Model 1570C		--	--	--
Kansas City	Resistivity meter, Bison Model 2390	Own	3	2	2
Omaha	1-channel seismograph, Bison Model 1575B	Own	2-3	2	2
	Resistivity meters, Associated Research Vibro-Ground Models 263 (1) and 293 (4)	Own	2	2	2
	Microearthquake recording seismographs Sprengnether Model MEQ00B (6)	Own	--	--	--
New Orleans	Borehole logger, Well Reconnaissance	Own	1	1	1

(Continued)

* Generally these personnel are geologists or engineers who perform geophysical surveys or interpretation as a part of their overall duties.

Table 1 (Concluded)

District	Equipment	Own or Rent	Typical* Crew Size	Qualified* Operators	Qualified* Interpreters
St. Louis	12-channel seismograph, Nimbus ES-120F	Own	3	2	1
	Resistivity meter, Bison Model 2390	Own	3	2	2
	Radar	Rent	2	1	1
	Borehole logger, Gearhart-Owen Widco Model 1200	Own	1	4	2
	3-channel blast seismograph, Sprengnether Model VS-1200	Own	1	1	1
	Subbottom Profiling	Rent	--	--	2
Vicksburg	Resistivity meter, Bison Model 2350	Own	2	2	2
	Borehole loggers, Well Reconnaissance, Model 8036 Log Master, Model 141-B Mineral Logging System, Model 1501	Own	1	4	6
Huntington	1-channel seismograph, Bison Model 1570B	Own	2	3	3
	1-channel blast Seismograph, Sprengnether Model VS-1100	Own	1-2	3	3
	Resistivity meter, Bison Model 2350	Own	2	3	2
	Borehole logger, Well Reconnaissance	Own	2	3	2
Louisville	2-channel seismograph Bison Model 1750B	Own	2	3	2
	Resistivity meter, Bison Model 2350B	Own	2	3	2
	Borehole logger, Gisco Keck Model R93	Own	2	2	2
Nashville	1-channel seismograph, Bison Model 1570C	Own	2	7	7
	Borehole loggers, Well Reconnaissance Model 8036; Well Reconnaissance Model 10406 (portable)	Own	1	5	7
Norfolk	1-channel seismograph, Bison Model 1570C	Own	3	1	1
	Bottom profiler, Raytheon RTT1000A	Own	3	3	1
	Side-scan sonar system, Klein Model 520	Own	3	3	1
	Resistivity meter, Bison Model 2350	Own	2	3	1
Baltimore	12-channel seismograph, Dresser SIE Model RS-4	Own	2	1	1
	Ground-water temperature profiler	Own	2	2	3
	Borehole logger, Well Reconnaissance Model 8036	Own	1	3	3
Philadelphia	1-channel seismograph, geochrone Thiokol	Own	2	2	2
	Resistivity meter	Own	2	2	1
Galveston	Borehole logger, Well Reconnaissance Model 10406 Geo-Logger	Own	--	--	--
Fort Worth	1-channel seismograph, Bison	Own	--	--	--
	Electric logging units	Own	--	--	--
Little Rock	1-channel seismograph, Geometrics Model ES 125	Own	2	1	1
	Resistivity meter, Soil Test, Model R-40C	Own	2	1	1
Tulsa	Resistivity meter, Michmo	Own	1	3	3
	Resistivity meter, Bison Model 2390	Own	3	3	3
	Borehole logger, Logmaster Model 654B-HKO	Own	3	3	3
Missouri River Div. Laboratory	Borehole logger, Well Reconnaissance Model 10406	Own	2	1	1
	1-channel seismograph, Nimbus ES-1	Own	2	1	1
	12-channel seismograph	Own	2	1	1
	Electrical resistivity Gish-Roomey Model 9	Own	4	1	1
	Crosshole seismic equipment	Own	2	1	1
	Electromagnetic conductivity	Rent	2	2	1
	Magnetometer	Rent	2	2	2
New England Division	1-channel seismograph, Soil test Model MD-9A	Own	2	2	2
	Borehole Caliper, Gisco Model DR-1992	Own	2	2	2

Table 2

Geophysical Equipment Inventory Responding Corps of Engineers Districts

Equipment Classification	Number in 26 Districts
Recording interval timers	1
1-channel seismographs	14
2-channel seismographs	1
6-channel seismographs	1
9-channel seismographs	1
12-channel seismographs	9
All seismographs	27
Radio-link seismometer	1
1-channel blast vibration recorder (seismograph)	2
3-channel blast vibration recorder (seismograph)	2
Microearthquake recording seismometers	6
Resistivity meters	20
Radars	1
Gravity meters	1
Magnetometers	3
Bottom profiler	1
Subbottom profiler	1
Side-scan sonar	1
Ground-water temperature profiler	1
Borehole logging systems	17

Geophysical contractors

22. Successful use of geophysical contractors (including other Government organizations) depends on several factors, such as (a) competence and dependability of the contractor, (b) ability of District personnel to prepare a contractual scope of work which adequately specifies the objectives of the work and the minimum acceptable performance standards for the contractor, (c) ability of District personnel to specify the work to be performed while still allowing the contractor sufficient flexibility to adapt field procedures to specific site conditions, (d) ability of District personnel to effectively monitor the quality of work performed, and (e) availability of qualified personnel for reviewing and assessing the results of the contractor's work. Table 3 lists contractors used within the past 10 years by the Districts (grouped by district). The list of contractors contains individual consultants, independent geophysical companies, geophysical groups that are part of larger companies, and Government agencies.

Geophysical methods

23. The geophysical methods which have been utilized by the Districts in recent years are summarized in Table 4. An x indicates that the method at the top of the column has been applied; other descriptions are given when deemed necessary for completeness. Seismic refraction is the most used geophysical method by the Districts, and the gravity, magnetic, and EM methods are the least used methods.

Identified Foundation Conditions Warranting Additional Investigations at Existing Structure Sites

24. Identified existing structure foundation conditions warranting additional study generally fall in the following categories: seepage, solution feature delineation in karst area, mapping or detection of cavities (voids) or joints beneath concrete structures, mapping stilling basin conditions underwater, determination of subsurface conditions at shallow water-covered sites, mapping of faults beneath structures, assessment of levee, and levee foundation conditions. Many of these problem categories are interrelated for specific cases. For example, anomalous seepage beneath a structure or through the abutments is commonly associated with solution features in karst areas or with fault (shear) zones passing through the foundation of a structure. Also, the problem of detecting voids beneath stilling basins is

Table 3

Use of Geophysical Contractors by the Corps of Engineers Districts

District	Contractor	Times Used	Geophysical Methods
Los Angeles	WES	2	Electrical resistivity Seismic crosshole Seismic refraction
	Harding Lawson Associates	1	Seismic crosshole Seismic downhole Seismic refraction
	Woodward-Clyde Consultants	2	Seismic crosshole Seismic downhole Seismic refraction Seismic reflection
	Fugro (ERTEC)	1	Seismic crosshole Seismic downhole Seismic refraction
	Dames and Moore Inc.	1	Seismic reflection
San Francisco	J. H. Kleinfelder	1	Electrical resistivity
	Harding Lawson Associates	1	Electrical resistivity
	WES	1	Seismic refraction Seismic crosshole Seismic uphole/downhole
Sacramento	Bailey Scientific Co.	2	Seismic Refraction
	Geo-Hydro Data	1	Borehole logging
	Welenco	1	Borehole logging
	Welex	1	Borehole logging
	Birdwell	1	Borehole logging
	Schlumberger	1	Borehole logging
	Seattle District (CE)	1	Seismic reflection
	Harding Lawson Associates	2	Seismic refraction
	WES	6	Seismic refraction Seismic crosshole Seismic uphole/downhole Surface seismic vibratory

(Continued)

(Sheet 1 of 5)

Table 3 (Continued)

District	Contractor	Times Used	Geophysical Methods
Jacksonville	WES	1	Seismic refraction Electrical resistivity
	Hydrosurveys	1	Subbottom seismic profiling
	Ocean Seismic Surveys/ Alpine Geophysical	1	Subbottom profiling
	CERC/EG&G	1	Subbottom profiling
Mobile	Weston Geophysical	1	Seismic refraction
	WES	1	Self potential
Savannah	Skidaway Institute of Oceanography	1	Subbottom profiling
Wilmington	Technos Inc.	2	Radar Electromagnetic conductivity Microgravity Seismic reflection
	Ocean Surveys Inc.	1	Seismic reflection
	Alpine/Ocean/Seismic Surveys Inc.	1	Seismic reflection
Walla Walla	WES	2	Self potential Seismic refraction Seismic crosshole Seismic uphole/downhole
	ERTEC	2	Seismic crosshole seismic uphole/downhole
Portland	GeoRecon International	1	Seismic refraction Seismic downhole
	Foundation Sciences Inc.	1	Seismic refraction
	Gasch and Associates	1	Seismic reflection Seismic refraction
	WES	1	Seismic refraction Seismic crosshole Seismic downhole
	Nortech Inc.	1	Subbottom seismic profiling, side-scan sonar

(Continued)

(Sheet 2 of 5)

Table 3 (Continued)

District	Contractor	Times Used	Geophysical Methods
Alaska	Harding Lawson Associates	1	Seismic methods
	Down Engineers	1	Seismic methods
	Golder Associates	1	Magnetic surveys Seismic methods Electrical resistivity Gravity survey
	Woodward-Clyde Consultants	1	Magnetic survey Seismic methods Electrical resistivity Gravity survey
Seattle	Endicott and Associates	1	Seismic refraction
	Northwest Geophysics Inc.	2	Gravity modeling Magnetic modeling
Omaha	Birdwell	1	Borehole logging (3-D velocity, gamma-gamma, gamma-neutron, electrical)
	Bechtold Drilling Co.	1	Borehole logging
	MRD Laboratory	2	Electrical conductivity Magnetometer Borehole logging
Kansas City	Kenneth Stokoe	1	Horizontal shear wave survey
	Orion Inc.	1	Magnetometer
	MRD Laboratory	3	Crosshole seismic surveys
Buffalo	Woodward-Clyde Consultants	1	Echo sounding Side-scan sonar Seismic reflection
	S.A. Alsup Assoc./H&A Consultants of NY	1	Echo sounding Seismic reflection
	Shannon and Wilson Inc.	1	Seismic refraction
	Dames and Moore Inc.	1	Seismic refraction
Rock Island	MRDL	1	Electrical resistivity
	Davenport/Hadley	1	Radar Self potential Electrical resistivity
	CRREL	1	Radar

(Continued)

(Sheet 3 of 5)

Table 3 (Continued)

District	Contractor	Times Used	Geophysical Methods
Memphis	WES	1	Seismic crosshole Seismic uphole/downhole Seismic refraction
St. Louis	Woodward-Clyde Consultants	1	Electrical resistivity
	WES	6	Seismic crosshole Seismic uphole/downhole Seismic refraction Electrical resistivity Subbottom profiling
	Geophysical Survey Systems	1	Radar
	McClelland Engineers	2	Electrical resistivity
	US Geological Survey	2	Subbottom profiling
Vicksburg	WES	5	Electrical resistivity Seismic crosshole Seismic uphole/downhole Seismic refraction Subbottom profiling
	Shannon and Wilson	2	Seismic refraction Electrical resistivity
Huntington	Muenon and Associates	1	Echo sounding
	WES	1	Seismic refraction Blast vibration monitoring
Pittsburgh	Geoprobe	1	Borehole television
Nashville	Charlene Well Services	1	Borehole logging
	WES	2	Seismic crosshole Seismic uphole/downhole Seismic refraction Self potential
Albuquerque	F. M. Fox Inc.	1	Seismic refraction
	WES	1	Seismic refraction
Fort Worth	Sigma Geoservices	1	Seismic reflection
	Davenport/Hadley	1	Self potential
	WES	1	Seismic refraction Seismic attenuation

(Continued)

(Sheet 4 of 5)

Table 3 (Concluded)

District	Contractor	Times Used	Geophysical Methods
Little Rock	WES	3	Electrical resistivity Seismic refraction Self potential EM conductivity Magnetometer
Tulsa	Geoprospectors Inc.	1	Seismic refraction
	Seismograph Services Inc.	1	Seismic refraction
Philadelphia	US Geological Survey	1	Seismic reflection Electromagnetic conductivity
Baltimore	Federal Highway Admin.	1	Borehole television
	US Bureau of Mines	1	Borehole television
New York	WES	1	Self potential Electrical resistivity
Norfolk	Huntec Limited	1	Seismic reflection
Huntsville Division	WES	2	Seismic background noise measurements Seismic refraction Seismic surface vibratory Self potential Electrical resistivity
New England Division	Weston Geophysics, Inc.	5	Seismic reflection Seismic refraction Radar
	Ocean Surveys, Inc.	9	Seismic reflection Seismic refraction
	S. A. Alsup and Assoc.	3	Seismic reflection Seismic refraction

(Sheet 5 of 5)

Table 4

Geophysical Methods Used by the Corps of Engineers Districts

District	Seismic Reflection	Seismic Refraction	Electrical Resistivity	Gravity	Magnetic	EM Radar	Borehole Logging
Tulsa		X*	X				
Little Rock	X	X	X	X	X	X	X
Fort Worth	X		SP**				
Galveston							X
Omaha					X	X	X
Kansas City	X	X			X		
Los Angeles	X	X	X				
San Francisco		X	X				
Sacramento	X	X					X
Portland	X	X					
Seattle	X	X		X	X		
Walla Walla		X	X,SP				X
Alaska	X	X	X	X	X		
Philadelphia	X					X	
Baltimore							X
New York			X,SP				
Norfolk	X		X,SP				

(Continued)

* X = District has used the indicated geophysical method.
** SP = Self-potential method.

Table 4 (Concluded)

District	Seismic Reflection	Seismic Refraction	Electrical Resistivity	Gravity	Magnetic	EM Radar	Borehole Logging
Buffalo	X	X					
Detroit		X	X				
Rock Island		X	X,SP			X	
Huntington	X	X					X
Pittsburgh							X
Nashville		X	SP				X
Louisville		X	X				X
Huntsville Division		X	X,SP				
Memphis		X					
St. Louis		X	X				X
Vicksburg		X	X				X
Wilmington	X	X		X		X	
Jacksonville	X	X	X				
Mobile		X	X,SP				
Savannah	X			X			X
New England Division	X	X				X	
Total: Using method by reporting Districts	15	24	17 (8 SP)	5	5	6	13

generally complicated by the fact that the slabs are water-covered and the stilling basins cannot be de-watered. The most commonly cited problems are anomalous seepage and the need to investigate foundation conditions beneath water-covered concrete structures.

25. The problem of levee and levee foundation condition assessment is complicated by the scale of the problem, i.e., lengths of many thousands of feet. Similar problems are presented by structures such as breakwaters and jetties in the coastal environment. Many times construction details and design drawings are nonexistent or incomplete for older structures. Conventional exploration techniques are prohibitively expensive for application to this type structure.

26. Two other conditions were identified in the survey responses which are very difficult to address. The first condition relates to the common occurrence of an open bedding plane at the structure/top of rock contact or in the rock very near the contact. In the absence of staining or weathering on the parting, it is very difficult to determine if the parting is induced by stress release as a result of drilling or is present in the undisturbed condition. Another problem is the difficulty in verifying the existence of thin clay seams in shales or sediments with shaley partings. Often there is evidence of clayey materials, but the exact nature of the seam in the subsurface is uncertain; i.e., is the clayey material (a) the remains of a thicker seam, (b) a thin shale seam softened by drilling, (c) an accumulation of fines from the drilling fluid intruding an open seam, or (d) actually a thin clay seam in situ.

Notable Applied Research Efforts

27. Because of the nature of work performed by and sources of funding for the Corps Districts, e.g., specific construction projects and operations and maintenance work, there is little opportunity, motivation, or mandate to conduct or fund research efforts directly. There are two recent cases, however, of applied research efforts which were funded by the Wilmington and Little Rock Districts. Only brief descriptions are given here; for details of the research, the District Geologists should be contacted.

28. The Wilmington District recently issued a Request for Proposals (RFP) to accomplish detection and monitoring of potential sinkhole features

along the Military Ocean Terminal Sunny Point (MOTSU) Access Railroad using geophysical methods. The RFP contained considerable details regarding the geology of the MOTSU area (approximately 20 miles southwest of Wilmington, NC) and the geotechnical problems affecting the railroad. Development of sinkhole features under or adjacent to the railroad occasionally interrupts rail service. The defined purposes of the requested surveys are to (a) define potential collapse features, (b) define the top of rock surface, and (c) monitor specifically selected targets on a quarterly or semiannual basis for a period of 2 years following the initial surveys. The RFP listed several geophysical surveys and stated that the proposals could include one or more of the methods for the test/demonstration phase and the production/monitoring phase. Presumably the results of the test/demonstration phase would be used to select the one or perhaps two methods best suited for the production/ monitoring phase. The results of the periodic monitoring surveys will be used to identify the progressive development of sinkhole features and investigate the feasibility of using the geophysical methods to provide advance warnings of impending sinkhole collapse. The RFP gave considerable flexibility to the proposers and stated that estimated cost would not be the primary deciding factor in contractor selection. It was clear from the five proposals received that the contractors were not accustomed to responding to applied research RFP's or did not believe that cost would not be the deciding factor, since the scopes of work proposed by several of the contractors were not very imaginative and too limited to adequately address the problem. The proposal which was accepted was good, and the contractor is capable of good work. Results from this District-sponsored research effort should provide a very valuable case history demonstrating the capability of various geophysical methods for detecting anomalous conditions and for monitoring the development of conditions in foundations which may threaten structures.

29. An effort to evaluate shallow, high-resolution seismic methods and microgravimetry for assessment of complex structural foundation conditions at Beaver Dam, Ark., was recently jointly funded by Little Rock District and the REMR Research Program. Dike 1 at Beaver Dam is founded on cavernous limestone and dolomite and has experienced anomalous seepage despite pre- and postconstruction grouting programs. In addition, the dike straddles a graben with at least 200 ft (60.98 m) vertical offset along the bounding faults. Thus the targets for assessment by the geophysical methods include solution-widened

joints and cavities, an irregular top of rock, soil and rock interfaces within the graben, fault zone detection and mapping, and the overall geological structure of the graben. The District recognized the potential for the applied research to contribute not only to its own assessment program but to the Corps' capabilities in general. Results of the work will be published as REMR reports.

PART IV: GEOPHYSICAL CAPABILITIES OF THE CORPS OF ENGINEERS LABORATORIES

30. There are nine Corps of Engineers research laboratories: the Hydraulics (HL), Geotechnical (GL), Structures (SL), Environmental (EL), and Information Technology Laboratory (ITL) and the Coastal Engineering Research Center (CERC), all at the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.; the Engineer Topographic Laboratory (ETL), Fort Belvoir, Virginia; the Cold Regions Research and Engineering Laboratory (CRREL), Hanover, N. H.; the Construction Engineering Research Laboratory (CERL), Champaign, Ill. Extensive geophysical capabilities exist at the GL and CRREL; fewer, more specialized geophysical capabilities exist at EL, CERC, and SL. This section of the report will concentrate on engineering and ground-water geophysics capabilities of the laboratories and will review personnel expertise, in-house equipment, and points of contact. Geophysics research which is not directly within the scope of engineering geophysics will not be discussed.

Geotechnical Laboratory, Waterways Experiment Station, Vicksburg, Mississippi

31. Geophysical capability in GL is in the Earthquake Engineering and Geophysics Division (EEGD) and the Engineering Geology and Rock Mechanics Division (EGRMD). EEGD has general engineering geophysics capability and interests, and EGRMD capability and interests are primarily in the areas of marine (waterborne) geophysics and borehole geophysical logging for rock mechanical and hydrogeological applications. There are 13 geophysicists in GL and at least 8 others (geologists and civil engineers) with training and experience in geophysics.

Points of contact

32. The general point of contact is Chief, EEGD, (FTS 542-2658). Specific points of contact and their areas of expertise are given in Appendix B.

In-house equipment and capability

33. Table 5 lists the major items of geophysical equipment in GL. Some outdated equipment is not included in the list.

34. GL performs a wide variety of geophysical surveys using in-house and rental equipment. Also, GL occasionally contracts for geophysical

Table 5

Geophysical Equipment--Geotechnical Laboratory

Item	Manufacturer
12-channel seismographs (2), Model 1210F	EG&G
Digital recorders (2), Model G7245	EG&G
24-channel seismograph, Model RA-49R	SIE
24-channel seismograph, Terraloc	ABEM
1-channel seismograph, Model 1575B	Bison
Blast vibration recorder, Model VS-1100	Sprengnether
Downhole vibrators (2), Model DV-1	Mark Products
Truck-mounted surface vibrator, "Vibroseis"	Failing
Surface vibrator, 2 KIP	WES
Air gun seismic source	Bolt
Blasters (2), Model FS-10	Reynolds
Downhole drift tool	OWL
OMNI IV Tie-line magnetometer and vertical gradiometer	EDA
Electrical resistivity meter, Terrameter SAS300 and SAS200 Booster	ABEM
Electrical resistivity meter, Model 2350B	Bison
Terrain conductivity meter, Model EM 34-3	Geonics
Gravimeter, Model D-130	LaCoste & Romberg
Water quality meter	YSI
Marine magnetometer, Model G-866	EG&G
Subbottom seismic profiling systems (2)	EG&G, ORE
Borehole geophysical logging system (caliper, natural gamma, SP, resistivity, gamma-gamma, neutron, fluid sampler, temperature)	Well Reconnaissance
3-D velocity logger	Birdwell
Televiewer	Simplex

geophysical surveys. Table 6 summarizes the types of geophysical surveys performed by GL and the in-house expertise in each area.

Scope of work

35. Geophysical projects undertaken by GL are of four types: (a) routine field studies for the Corps Field Operating Agency (FOA's) or other Government agencies, which are generally 1 year or less in total duration; (b) small-scale basic or applied research projects, typically 1 year in duration; (c) multi-year basic or applied research efforts; (d) high priority special problem studies, frequently high intensity, short time frame projects. Examples of routine field studies are given by Llopis and Wahl (1982) which include an in situ seismic investigation of Black Butte Dam for the Sacramento District, a geophysical investigation in support of a comprehensive seepage analysis of Clearwater Dam for the Little Rock District by Koester et al. (1984), and a microgravity survey of Wilson Dam powerplant switchyards for the Tennessee Valley Authority by Butler and Yule (1984). Some of the routine field studies involve geophysical techniques, such as microgravity and special seepage mapping procedures which have been developed or greatly advanced by research programs in GL and are not readily available from contract sources at present. An example of a 1-year applied research project is that of Franklin (1980), which is a study of interpretation procedures for a specialized seismic method. Examples of multi-year research programs have been mentioned previously (Part I) and include the present REMR project, the cavity detection and delineation research program, and the analytical and data processing techniques research project. Another multi-year research and development project involves the advancement of the state of the art in instrumented penetrometers as described by Cooper and Franklin (1982) and Cooper et al. (1987). An example of a high-priority special problem study is the development and deployment of a specialized passive seismic detection system developed for location of intrusion tunnels in Korea; this short time frame project builds on and resulted from previous cavity and tunnel detection research such as already referenced and as described by Ballard (1982).

36. Personnel of GL possess expertise in varying degrees in most areas of applied geophysics. Thus GL personnel can and are willing to provide advice and limited consulting services to Corps FOA's and other Government agencies regarding feasible applications of geophysics, scope of work preparation, proposal evaluation and contractor selection, and contractor product

Table 6

Geotechnical Laboratory In-House Capability and Expertise

Applied Geophysics

Geophysical Method	Equipment Rent (R)/ Own (O)	Average Crew Size	Personnel: Qualified Operators	Personnel: Qualified Interpreters
Seismic refraction	O	3-4	10	8
Seismic reflection	O	3-4	3	3
Crosshole/uphole/ downhole seismic methods	O	2-4	6	8
Vibratory surface wave methods	O	3	8	6
Seismic attenuation/ ground motion studies	O	3-6	3	5
Electrical resistivity	O	3-4	6	6
Self-potential (SP)	O	2	6	6
Ground penetrating radar	--	--	--	3
Electromagnetic conduc- tivity (induction)	O	2	4	3
Transient electromagnetic	R	2-3	2	2
Magnetic	O	2	4	3
Microgravity	O	2	3	3
Borehole geophysical logging	O,R	2	3	4

assessment (assistance in interpretation of results). Services which require less than a two man-day effort are generally gratis. Services which require more time or possibly travel generally must be funded by the requestor, although occasionally the personnel contacted may have a research project relevant to the requestor's problem, and more extensive support can be provided at no cost to the requestor.

Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

37. As the name implies, CRREL is the Army's specialized laboratory for cold regions research and engineering. In relation to applied geophysics, CRREL's primary mission is the investigation of the properties of snow, ice, frozen ground, and permafrost, and the development of advanced state-of-the-art geophysical survey methods to characterize the above special geological materials and conditions. Implicit in this specialized mission is the development of new and adaptation of old geophysical methods for better applicability to cold regions.

38. Geophysical capability in the CRREL are primarily in the Snow and Ice and Geophysical Sciences Branches of the Research Division and Geotechnical and Ice Engineering Research Branches of the Experimental Engineering Division (EED). There are eight geophysicists at CRREL and at least eight other personnel (geologists, physical scientists, and engineers) with training and experience in geophysics.

Points of contact

39. The general point of contact is Technical Director, CRREL (Telephone 603-646-4201). Specific points of contact and their areas of expertise are given in Appendix B.

In-house equipment and capability

40. Table 7 lists the major items of geophysical equipment at CRREL.

41. The types of geophysical surveys performed by CRREL and the in-house expertise in each area are summarized in Table 8.

Scope of work

42. Virtually all the discussion under Scope of Work for GL, WES, regarding types of projects and the ways projects are initiated, holds for the CRREL and will not be repeated. Because of its specialized mission, CRREL has significantly advanced the state of the art in applications of those

Table 7

Geophysical Equipment, Cold Regions Research and Engineering Laboratory

Item	Manufacturer
24-channel seismograph, Model DSS10A	Geosource
1-channel seismograph	Geometrics
Master/slave units for remote, explosive detonation	Input-Output
Induced polarized system, Model M3	Huntec
Magnetometer	Geometrics
VLF earth resistivity meters, Model EM-32, Model EMR-16 (2)	Geonics
Terrain conductivity meters, Model EM-31, Model EM-34	Geonics
Ground penetrating radar systems	Xadar GSSI (2)

Table 8

CRREL In-House Capability and Expertise

Applied Geophysics

Geophysical Method	Equipment Rent (R)/ Own (0)	Average Crew Size	Personnel: Qualified Operators	Personnel: Qualified Interpreters
Seismic refraction	0	2	3	3
Seismic reflection	0	2	3	3
Seismic/acoustic noise measurements	0	2	2	2
Ground penetrating radar	0	2	3	5
Magnetic	0	1	4	1
VLF electromagnetic	0	1	2	1
Electromagnetic terrain conductivity	0	1	4	4

geophysical methods which are particularly suited to such problem areas as determining snow and ice properties, mapping sea and river ice thickness, locating ground ice masses, mapping permafrost depth, and general investigations in areas where the upper part of the ground may be frozen. Associated with its specialized mission, CRREL also conducts laboratory and field studies to investigate the influence of the cold regions environment on the performance of electromagnetic and seismic/acoustic sensor systems.

43. The ground penetrating radar method and determination of electromagnetic properties of snow, ice, and frozen ground are two areas in which CRREL has extensive experience and capability. Examples of studies involving the measurement of electromagnetic properties are given by Arcone and Delaney (1982), Delaney and Arcone (1982), and Morey, Kovacs, and Cox (1984). Examples of ground penetrating radar surveys performed for geotechnical and ground-water studies are given by Arcone and Delaney (1984) and Sellman, Arcone, and Delaney (1983). Ground penetrating radar has many applications for investigation of very shallow anomalous conditions such as cavities beneath pavement and for location of buried utilities. Examples of these applications can be found in publications by Kovacs and Morey (1983) and Bigl, Henry, and Arcone (1984). Typical of research and field studies utilizing other geophysical methods are the reports by Peck (1985) and Neave and Sellman (1983).

Coastal Engineering Research Center, Waterways Experiment Station, Vicksburg, Mississippi

44. CERC focuses on the solution of engineering problems within the coastal and shallow marine zone. The difficulties of applying conventional geophysical techniques in the shallow, and often turbulent waters of the marine environment have lead CERC to specialize in the use of acoustical instruments. The data generated is used to interpret structure condition and provide information on surface and subsurface sediments. This information may be used in place of or to supplement data from more conventional geophysical instruments. In order to fulfill its mission, CERC has applied side-scan sonar, subbottom profiler, and high resolution, shallow penetration, seismic reflection instrument technology.

45. Expertise in the use and evaluation of side-scan sonar for inspecting coastal structures lies primarily within the Prototype Measurements and

Analysis Branch (PMAB) and the Coastal Structures and Evaluation Branch of the Engineering Division. PMAB also has REMR work unit, "Evaluation of Damage to the Underwater Portion of Coastal Structures," which is advancing the state of the art in underwater inspection tools, including both acoustical and more conventional geophysical tools and techniques. The Coastal Processes Branch of the Research Division has personnel experienced in interpreting side-scan sonar and subbottom data to locate sediments and resources.

Points of contact

46. The general point of contact is Chief, CERC (FTS 542-2000). Specific points of contact and their areas of expertise are given in Appendix B.

In-house equipment and capability

47. Table 9 lists the major items of geophysical equipment at CERC.

48. The types of geophysical surveys performed by CERC and the in-house expertise in each area are summarized in Table 10.

Table 9

Geophysical Equipment, Coastal Engineering Research Center

Item	Manufacturer
Model 260 digital image side-scan sonar with 100 and 500 kHz towfish	EG&G
Model 530T/TH side-scan sonar 100 and 500 kHz towfish and 3.5 kHz subbottom profiler	Klein Associates

Table 10

CERC In-House Capability and Expertise Applied Geophysics

Geophysical Method	Equipment Rent (R)/ Own (O)	Average Crew Size	Personnel: Qualified Operators	Personnel: Qualified Interpreters
Side-scan sonar	O	2*	7	4
Subbottom profiler	O	2*	4	6

* Not including vessel operator.

Scope of work

49. The discussion under the Scope of Work for GL, WES regarding the types of projects and the ways projects are initiated also holds true for CERC and will not be repeated. The unique aspects of the coastal environment have lead CERC to concentrate its efforts on developing techniques for using acoustic tools for imaging coastal structures, bottom surface features, and subbottom cross sections. CERC has significantly advanced the state of the art in the use of side-scan sonar for inspecting all types of coastal structures (Clausner and Pope (in preparation)). A specific example of the level of detail possible during a side-scan sonar inspection can be found in Patterson and Pope (1983) and Morang (in preparation). Combinations of side-scan sonar, acoustic subbottom profiler, and high resolution shallow penetration seismic reflection data have been used by CERC to explore sand/gravel resources and examine geologic structure of the inner continental shelf. Meisburger (1979) provided an example of this type of operation.

50. CERC has limited experience with subaqueous nuclear density probes for measuring sediment density, particularly in dredged material disposal mounds. At this time the tool must still be considered experimental, although a reliable prototype model should be developed by the private sector in the near future.

PART V: SUMMARY AND RECOMMENDATIONS

51. There can be no really definitive conclusions from survey results such as presented in this report. This section will merely present a summary of key survey results, observations, and recommendations. Engineering geophysics has been widely used in the Corps of Engineers in the past. Frequently, however, the results of the geophysical applications have been inconclusive, not interpreted properly, or never utilized. There are several reasons for less than optimal utilization of engineering geophysics: (a) failure to properly incorporate engineering geophysics into the overall exploration, investigation, or assessment plan; (b) lack of experienced personnel in the office conducting the geophysical surveys or contracting for the work; and (c) poor contractor performance. There are indications in the survey results and in the experience of the authors that these problems are being rectified. Some of the reasons for the improved status of engineering geophysics are (a) an increasing number of personnel with formal training in geophysics, (b) better equipment, (c) availability of microcomputers for engineering geophysical data processing and interpretation, and (d) a growing number of problems facing the Corps for which engineering geophysical methods are the best or only viable approach (e.g., hazardous wastesite investigations and ordnance clearing operations).

52. The difficulty of obtaining funds for geophysical equipment purchase has prevented some Districts from acquiring the needed equipment for conducting in-house surveys. Leasing and borrowing equipments are options for those Districts without modern equipment. This report provides lists of points of contact in the Districts and Laboratories and lists of in-house equipment. If borrowing equipment proves to be unfeasible, then many of the points of contact can identify sources for equipment leasing. The survey results indicate that as a corporate entity the Corps of Engineers has considerable experience and database on geophysical contractor performance. This corporate database can and should be used as a guide in geophysical contractor selection. Also, the corporate experience should be used to properly specify contractor statements of work and to monitor and review contractor performance.

53. It is essential that District personnel obtain training in engineering geophysics. The training is important not only for those personnel

conducting surveys, but for those personnel monitoring and reviewing contractor performance. Districts with in-house geophysical expertise can provide training seminars. Training is sometimes provided as a service to clients by geophysical equipment manufacturers. Such training is particularly appropriate since it is tailored to the specific equipment purchased. Other training in the form of short courses is available from the US Geological Survey, Colorado School of Mines, and the Corps of Engineer PROSPECT program. Presently, engineering geophysics is included as part of PROSPECT courses such as the Drilling and Sampling Short Course and the semester long Engineering and Geology courses, but a full one-week engineering geophysics course is planned beginning in 1988.

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APPENDIX A: POINTS OF CONTACT IN THE CORPS OF ENGINEERS DISTRICTS FOR GEOPHYSICAL CAPABILITY AND PRACTICE SURVEY

District	Contact	Telephone (FTS)
Los Angeles	David Lukesh	798-5486
Sacramento	John T. Gewerth	448-3111
San Francisco	Ken Harrington	454-0369
Jacksonville	Thomas Thornton	946-1620
Mobile	John McFayden	434-2648
Savannah	Earl Titcomb	248-5300
Wilmington	Porter Morgan	671-4548
Walla Walla	Tilden McDowell	442-4530
Omaha	Douglas Pendrell	864-4494
Kansas City	John Moylan	758-3554
Buffalo	Thomas A. Wilkinson	473-2168
Chicago	James Knox	353-6498
Detroit	Ron Erickson	226-2226
Rock Island	Ronald Pearson	386-6445
St. Paul	Robert Whartman	725-7595
Portland	John Sager	423-6460
Memphis	Harold Smith	222-3238
New Orleans	Frederick L. Smith	862-1020
St. Louis	Gregory L. Hempen	273-5654
Vicksburg	George L. Hunt, Jr.	542-5639
Huntington	Robert Yost	924-5234
Louisville	Loren Christman	352-5730
Nashville	Joseph Melnyk	852-5685
Pittsburgh	Stuart B. Long	722-4124
Alaska	James L. Williamson	907-522-2718 (commercial)
Seattle	William Hancock	399-3711
Albuquerque	Jim McAdoo	474-2713
Galveston	John Cleveland	527-6089
Fort Worth	Mel Green	334-2223
Little Rock	Charles Deaver	740-5603
Tulsa	Arthur Burkhart	745-6168

District	Contact	Telephone (FTS)
New York	Michael Fedosh	264-9110
Norfolk	Jerry Swean	827-3669
Baltimore	A. Richard Price, Jr.	922-2004
Philadelphia	Roman Lazor	597-4820
New England Division	Ronald DeFilippo	839-7387

APPENDIX B: ENGINEERING GEOPHYSICS POINTS OF CONTACT IN THE CORPS OF ENGINEERS LABORATORIES

Geotechnical Laboratory, Waterways Experiment Station, Vicksburg, Mississippi

EEGD

Arley G. Franklin, Chief, EEGD, FTS 542-2658

Joseph R. Curro, Chief, Field Investigations Group (FIG), FTS 542-2127
General: seismic methods

Jose L. Llopis, FIG, FTS 542-3164
General: seismic methods, electrical resistivity, seepage, and contaminant mapping

Stafford S. Cooper, FIG, FTS 542-2477
Penetrometer methods for site investigations, and vibratory testing methods for structures and foundations

Dwain K. Butler, Research Group, FTS 542-2127
General: microgravity, electrical resistivity, electromagnetic methods, seepage, and contaminant mapping

Robert F. Ballard, Research Group, FTS 542-2201
Seismic methods for dynamic property determinations

EGRMD

Donald C. Banks, Chief, EGRMD, FTS 542-2630

James H. May, Chief, Site Characterization Unit, FTS 542-3395
Borehole geophysical logging for hydrogeological studies

William Murphy, Site Characterization Unit, FTS 542-3322
Marine geophysics (Magnetics, subbottom profiling, side-scan sonar)

James B. Warriner, Rock Mechanics Applications Group, FTS 542-3610
General: Borehole geophysical logging for rock mechanical studies

Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

RD

Donald Albert, Geophysical Sciences Branch (GSB), 603-646-4459
Seismology, Exploration Geophysics

Kenneth Jazek, GSB, 603-646-4100
Seismology, ground penetrating radar, remote sensing

Lindamae Peck, GSB, FTS 836-4100
Seismology

RD (Continued)

Steven Arcone, Snow and Ice Branch (SIB), 603-646-4368
Exploration Geophysics, electromagnetic methods, ground penetrating radar

Samuel C. Colbeck, SIB, 603-646-4257
Snow and ice properties

Harlan McKim, Geological Sciences Branch, 603-646-4479
Remote sensing

Charles Collins, CRREL-Alaska, 907-353-5180
Resistivity methods, borehole geophysical logging

EED

Paul V. Sellman, Geotechnical Research Branch, 603-646-4347
Geophysical techniques in permafrost studies, ground penetrating radar

Austin Kovacs, Applied Research Branch, 603-646-4411
Ground penetrating radar

Steven Daly, Ice Engineering Research Branch, 603-646-4218
Ground penetrating radar, frazil ice properties

Jerome Johnson, CRREL-Alaska, 907-353-5167
Attenuation of shock waves in snow

Coastal Engineering Research Center, Waterways Experiment Station, Vicksburg, Mississippi

CD

Thomas W. Richardson, Chief, CD, FTS 542-2019

J. Michael Hemsley, Prototype Measurements and Analysis Branch (CD-P)
FTS 542-2075
General: side-scan sonar

William M. Kurarski, CD-P, FTS 542-3515
Side-scan sonar, subbottom profiler

Joan Pope, Chief Coastal Structures and Evaluation Branch (CD-S),
FTS 542-3034
General: side-scan sonar

James E. Clausner, CD-S, FTS 542-2019
Side-scan sonar

Edward P. Hands, CD-S, FTS 542-2088
Side-scan sonar

CR

H. Lee Butler, Chief, CR, FTS 542-2405

Steven A. Hughes, Chief Coastal Processes Branch (CR-P), FTS 542-2026
General

Donald K. Stauble, Chief, Coastal Morphology Unit (CR-PM), FTS 542-2056
General

Fred J. Anders, CR-PM, FTS 542-3034
Subbottom profiling, side-scan sonar

Edward P. Meisburger, CR-PM, FTS 542-2078
Subbottom profiling, side-scan sonar

Steven G. Underwood, CR-PM, FTS 542-2819
Subbottom profiling, magnetometer surveys, side-scan sonar

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